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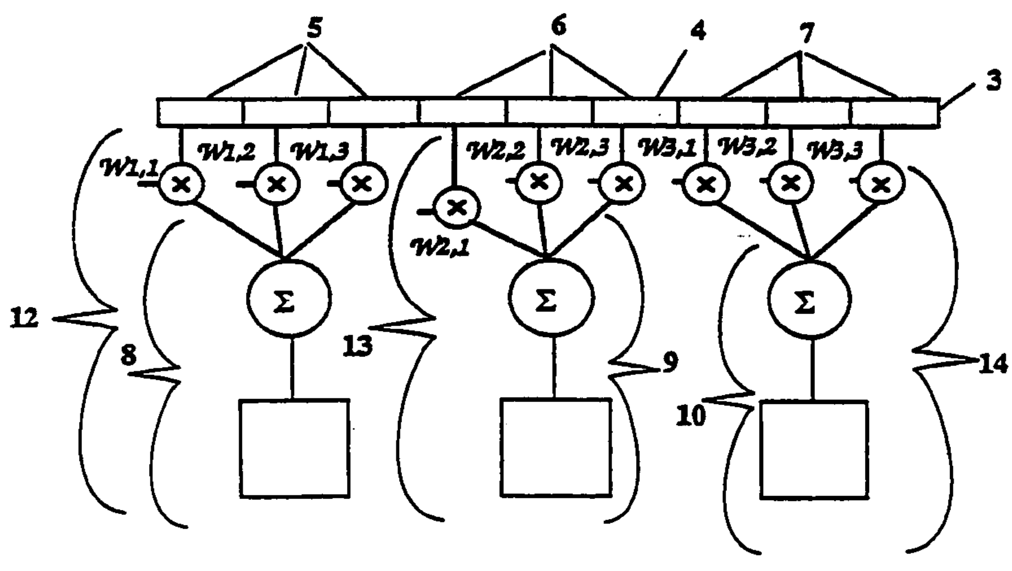

(57) Abstract

A method of forming from an antenna array of a first signal station a plurality of further signal stations each with an antenna array being a sub-array of the antenna array of the first signal station. The sub-arrays are formed by splitting the antenna array of the first signal station or alternatively interleaving the antenna array of the first signal station. Conversely, the first signal station can be formed by combining other signal stations where the other signal stations have associated antenna sub-arrays of fewer elements than the said antenna array.

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IMPLEMENTATION OF MULTIPLE APERTURES THROUGH ANTENNA INTERLEAVING AND SPLITTING

The invention disclosed herein relates to the utilisation of antenna arrays.

In providing a background discussion of antenna arrays reference will be made to receiving antenna arrays. It will be understood that transmitting antenna arrays are in principle the converse of receiving antenna arrays though design specifics may vary especially in regard to power handling capability.

Prior known systems do not provide for selective and controllable re-arrangement of array elements so that, for example, when received signal strength is low all elements are used for a single signal station and when received signal strength is high the elements of an antenna array are used in as smaller antenna arrays for a plurality of signal stations. This is discussed further below.

Further, it will be appreciated that antenna arrays and signal switching and processing means for antenna arrays are known. What is not and is the subject of this invention is that a signal antenna array can be reconfigured as multiple sub-arrays as desired and the performance of the sub-arrays for many applications is sufficient. Therefore enhanced flexibility and application can be achieved using the invention than has previously been known. With the example of Over the Horizon Radar establishments this means that a large and expensive antenna array can be used for many tasks simultaneously when the requirements, conditions or both allow yet when needed the whole antenna array can be used for a single task. It will be appreciated that the invention whilst applicable to Over the Horizon Radar establishments it is not limited to them.

The following patent specifications concern applications of antenna arrays: DE 18926277, Rücker, Wolfgang; US 4827270, Udagawa et al; US 4623894, Lee et al; GB 2164497, Mead, James B; US 4570165, Tsurumaru et al; GB 1282320, Huele, Hendrik Teunis; and, EP 0313057, Rosen, Harold A. However, all these concern fixed arrays which do not

allow for reconfigured of a single array as multiple sub-arrays when desired. Patent specification WO 91/01620 discloses an apparatus which provides for selection of one of a number of antenna array configurations but this is restricted to selecting one of a number of antenna field patterns not to provide a sub-array for independent use.

These patent specifications are not directed to the problem solved herein or to related problems. In fact, most are concerned with applications involving microwave electromagnetic radiation which are not subject to atmospheric effects encountered at lower frequencies to which, but not exclusively, the invention disclosed herein are directed.

A receiving antenna array is an antenna made up of a number of elements. The output of the antenna array is the summation of the outputs of the array elements. Phase, or time-delay and amplitude adjustment of the output signal of individual elements is necessary to ensure correct signal summation. The array pattern formed from summing the outputs is dependent on the signal adjustments prior to summation, the antenna element locations and the antenna element pattern. For convenience the carrier frequency for the antenna array output can be translated to an intermediate frequency where the adjustments and summation can be performed. In some applications the adjustments and summation can occur after conversion to digital numbers.

The array pattern is generally characterised by a number of parameters including beamwidth. Here beamwidth means the angular width between the angles where the response is -3dB with respect to the peak response. The beamwidth is approximately proportional to the inverse of the aperture length in wavelengths. With a fixed physical aperture length (metres), doubling frequency therefore halves the beamwidth. The gain of the antenna array also follows a similar trend. In this case the gain is also proportional to the aperture length in wavelengths when there is constant antenna efficiency.

For an array the spacing between the elements is normally based on the maximum operating frequency. The aim being to avoid spurious "grating

lobes". Thus when the frequency is halved, a similar array pattern is possible with half the number of elements at twice the spacing.

In the HF environment (about 6 to 30 MHz) the external noise power of a signal received by an antenna is characterised by a number of factors including frequency. For example the noise component is about 30dB higher at 6 MHz than at 30 MHz. Consequently the antenna array gain is often designed to meet an expected worst case scenario which, for a radar, involves a combination of the frequency dependent noise criteria and waveform parameters. The frequency associated with the worst case conditions is often near to the lowest frequency of operation. Because of the frequency dependence of the external noise, higher frequencies of operation lead to increased signal-to-noise ratio (SNR).

Another related factor for HF propagation is the frequency dependence of the range between a source and a receiver over which radio signals will start to propagate. Also for a given frequency there is a limited range extent that will give adequate propagation. Therefore more than one frequency is often required to maintain adequate propagation over a large range extent. The variation in ionospheric conditions leads to these frequencies changing with time in order to maintain propagation to a nominated range and associated range extent.

At least one object of the invention disclosed herein is to provide a means by which an antenna array can be reconfigured to more effectively adapt to changing conditions.

An antenna forms part of a receiving, transmitting or transceiving apparatus. An antenna has a connection to receiving or driving circuits depending upon the application of the antenna. An antenna array herein will be understood to mean an array of individual antennae combined to act as a conglomerate antenna. It will be appreciated herein that the term array elements refers to a individual antenna with a driven or driving element and associated if applicable passive elements.

Herein the term signal station is used to refer to an array of antennae and associated apparatus which are combined for the purpose of receiving, transmitting or transceiving on the same carrier frequency for all array

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elements. The term processing refers to signal stations excluding the associated antenna array. For the special case of receiving, a signal station also includes the case of a plurality of summations from the same array of antennae for the purpose of forming a plurality of beams.

Accordingly the invention can be said to reside in a method of re-arranging outputs to or inputs from antennae including the steps of combining with combining means a plurality of antennae and associated connection circuitry into a single antenna array or a plurality of antenna sub-arrays, changing as desired the combination of individual antennae forming the antenna array or antenna sub-arrays, and providing through processing means an output or an input for each antenna sub-array or for the antenna array.

In preference, the signal stations of the antenna sub-arrays are formed from the antenna array of the first signal station by either or both splitting or interleaving the antenna array.

Preferably, some of the sub-arrays are formed by interleaving the antenna array of the first signal station and others are formed by splitting the antenna array of the first signal station.

Alternatively, the invention may be said to reside in an assembly including a plurality of antennae and associated connection circuitry, combining means adapted to combine the antennae into a single antenna array or a plurality of antenna sub-arrays, the combining means being further characterised by being adapted so that the combination of individual antennae forming the antenna array or antenna sub-arrays are selectable and changeable as desired, and one or more processing means adapted to be connected through the combining means to the connection circuitry and provide an output or an input for each antenna sub-array or for the antenna array.

Preferably, the sub-arrays are either or both split or interleaved sub-arrays of the antenna array and for each sub-array there is a signal station.

In preference, the sub-arrays are formed by splitting the antenna array of the first signal station. Alternatively, the sub-arrays are formed by interleaving the antenna array of the first signal station. Further, some of the sub-arrays are formed by interleaving the antenna array of the first signal station and others are formed by splitting the antenna array of the first signal station.

It will be appreciated that the output signals associated with each antenna array element can be switched to be combined with other such outputs. Such switching and signal combining devices and techniques are known to the art, however, the forming of independent sub-arrays and multiple signal stations is not.

An antenna array divided into sub-arrays of adjoining elements is defined as a split array. By this means the antenna array is used for a plurality of individual and independent antenna sub-arrays which are independent signal stations. For a transmitting array the signal stations must use different carrier frequencies whereas a receiving array has no such restriction. For a split array the array aperture length for each signal station decreases with increasing numbers of sub-arrays. For example, splitting the array into two sub-arrays reduces the aperture by half.

An antenna array divided into sub-arrays where the elements of a sub-array are not adjoining array elements of the antenna array and of which the sub-array is a part is defined as an interleaved array. By this means the antenna array is used for a plurality of individual and independent interleaved sub-arrays which are independent signal stations. For a transmitting array the signal stations must use different carrier frequencies whereas a receiving array has no such restriction. Elements of separate sub-arrays may be adjoining. In the case, for example, of an antenna array sub-divided into two sub-arrays an element of sub-array A would be flanked by elements of sub-array B. The sub-array of the interleaved array has approximately the same aperture of the antenna array but with twice the element spacing. The sub-array of an interleaved antenna is expected to have approximately the same gain as the whole antenna array.

The invention can be said to reside in an assembly including:

a plurality of antenna array elements each adapted to effect reception or transmission of electromagnetic radiation and collectively being adapted to form an antenna array;

one or more processing means adapted to process signals received by it for transmission to an antenna array element or received from an antenna array element;

a plurality of controlled beam weighting circuitry means each associated with and connected to an element, each controlled beam weighting circuitry means providing a connection to processing means and being adapted to selectively and controllably adjust either or both the phase and amplitude of signals received from or sent to the connected element;

control means adapted to selectively and controllably connect one or more of the controlled beam weighting circuitry to a processing means thereby forming an antenna sub-array in respect of that processing means, if some of the controlled beam weighting circuitry are not connected to that processing means selectively and controllably connecting those to one or more other processing means thereby forming associated antenna sub-arrays, and the control means being further adapted to selectively change the processing means to which any one of the controlled beam weighting circuitry is connected.

In another form, the invention can be said to reside in a method of re-arranging connections to outputs to or inputs from controlled beam weighting circuitry means associated with individual antenna array elements including the steps of:

effecting reception or transmission of electromagnetic radiation with a plurality of antenna array elements;

processing with one or more processing means signals received by the processing means for transmission to an antenna array element or received from an antenna array element;

selectively and controllably, with a plurality of controlled beam weighting circuitry means, adjusting either or both the phase and amplitude of

signals received from or sent to the connected element where each element has one of the controlled beam weighting circuitry means associated with and connected to it;

selectively and controllably connecting one or more of the controlled beam weighting circuitry to a processing means thereby forming an antenna sub-array in respect of that processing means, if some of the controlled beam weighting circuitry are not connected to that processing means then selectively and controllably connecting those to one or more other processing means thereby forming associated antenna sub-arrays, and selectively changing the processing means to which any one of the controlled beam weighting circuitry is connected.

The invention disclosed herein is applicable to a number of applications involving transmitting or receiving or both of radio signals. Such applications are not limited to applications concerned with only one frequency band. The invention will now be described as it is exhibited by a preferred embodiment concerning radar operating at HF frequencies (about 6 to 30 MHz), such as Over-the-Horizon Radar, with reference to the accompanying Figures. It will be understood that this embodiment is not limiting on the invention.

FIG. 1 illustrates, in simplified block diagram form, a signal station connected to an antenna array,

FIG. 2 illustrates, also in simplified block diagram form, a plurality of signal stations connected each to a sub-array of a split antenna array, and

FIG. 3 illustrates, also in simplified block diagram form, a plurality of signal stations connected each to a sub-array of an interleaved antenna array.

In FIG. 1 a signal station 1 is illustrated in a known arrangement. The signal station 1 could be a receiving, transmitting or transceiving signal station. As such the signal station 1 includes processing means 2 and an antenna array 3.

The antenna array 3 comprises a plurality of elements 4, in this case nine. Here only three out the nine elements 4 are labelled. The elements 4 include in the case of a receiving array, the antenna elements and receiver which translates the signal to an appropriate intermediate frequency. The output of each element is weighted by beam weights W_1 to W_9 as shown. Further the processing means 2 includes signal amplitude and phase adjustment and summing means 11 to sum the output of the antenna array elements 4.

In the case of a receiving array, the operations formed by the processing are given by the following equation.

$$r_j = \sum_{i=1}^{N} W_{ij} s_i$$

where s_i is the i th element output, N is the number of elements, W_{ij} is the amplitude and phase adjustment for the j th beam, and r_j is the output for the j th beam.

Now turning to FIGS. 2 and 3. As can be seen the antenna array 3 is divided into three sub-arrays 5, 6 and 7 each consisting of 3 array elements 4. Here only one out the nine elements 4 is labelled. Beam weighting is performed as before though with respect to the requirements of the particular sub- array here shown as $W_{1,1}$, $W_{1,2}$ ... $W_{3,3}$. Sub-arrays 5, 6 and 7 are connected to processing means 8, 9 and 10 respectively. The effect of this is that a single antenna array 3 is used to form in effect three signal stations 12, 13 and 14 which can be independent from each other.

Control means are incorporated into the processing means and are adapted to effect selective and controlled re-arrangement of the connections from the antenna elements to form signal stations.

The operations for processing with a split antenna receiving array where the sub-arrays equally divide the antenna are given by the following equation.

$$r_{j,k} = \sum_{i=1}^{\frac{kN}{K}} W_{ijk} s_a$$

$$a = i + \frac{(k-1)\,N}{K}$$

where k is split antenna index, k=1,..,K.

The operations for processing an interleaved antenna receiving array where the sub-arrays equally divide the antenna are given by the following equation.

$$r_{j,x} = \sum_{i=1}^{\frac{N}{L}} W_{ij} s_{(i-1)x+l}$$

where x is interleaved antenna index, x=1,..,L.

The forming of the signal stations can be, though not necessarily, achieved through switching means which can allow the number of signal stations and the number of elements forming each sub-array to be varied. As circumstances dictate a plurality of signal stations can be converted into a single signal station using the whole of the antenna array 3 as depicted in FIG. 1.

It will be understood that the number of sub-arrays can be any from two to the number of array elements and the number of array elements in each sub-array need not be equal.

The benefits of this is that the radar comprising of a single antenna array can be used as a plurality of individual radars. For an Over-the-Horizon Radar operating in the HF band, a split antenna is used when operating

at the upper end of the HF band. The environment allows the reduced antenna gain because of the lower noise while the reduced aperture allows the scan rate to be increased because of the larger beamwidth. Aperture splitting overcomes some of the beamwidth reduction with increasing frequency.

When the radar is operated at the lower frequencies an interleaved array is used. This maintains the antenna gain required and adds multiple frequency capability to enhance the radar scanning performance. Both splitting and interleaving allow multiple radars with greater scanning capability.

Another benefit of this results from the plurality of individual radars. This could allow coverage of a region of the earth with an effective course beam using a signal station using a sub-array antenna which can detect the presence of a potential target. Then by switching to a signal station using the whole of the antenna array more accurate assessment of the position of the target can be made than possible with a signal station using a sub-array of the whole antenna.

Another benefit of the invention is that when propagation conditions are favourable a plurality of independent signal stations can be formed with a potential increase in performance by having the greater number of signal stations. In the case of communication systems this means that transmission throughput could be increased.

Alternatively, signal stations each using part of an antenna array could cover the same area of a radar but each operating at different frequencies. This can be used to alleviate atmospheric effects on signal transmission at different frequencies and in effect allows for parallelism in a system.

It will be appreciated that the invention described herein could be exhibited in a number of embodiments which would be apparent to a person skilled in the art. All such embodiments would fall within the spirit of the invention disclosed herein.

It will be apparent from the above that the invention could provide a means to alleviate one or more of the disadvantages associated with antenna arrays and also provide a more efficient means to use an antenna array than hitherto has been known.

1. An assembly including:

a plurality of antenna array elements each adapted to effect reception or transmission of electromagnetic radiation and collectively being adapted to form an antenna array;

one or more processing means adapted to process signals received by it for transmission to an antenna array element or received from an antenna array element;

a plurality of controlled beam weighting circuitry means each associated with and connected to an element, each controlled beam weighting circuitry means providing a connection to processing means and being adapted to selectively and controllably adjust either or both the phase and amplitude of signals received from or sent to the connected element;

control means adapted to selectively and controllably connect one or more processing means to the controlled beam weighting circuitry means such that any one controlled beam weighting circuitry means is connected to one processing means, and the control means being further adapted to selectively change the processing means to which anyone of the controlled beam weighting circuitry means is connected.

2. An assembly as in claim 1 wherein the control means is adapted to effect either or both antenna array splitting and antenna array interleaving where each of the said sub-arrays is either a split array or an interleaved array.

3. An assembly as in either claim 1 or claim 2 further characterised by the antenna array elements being substantially identical.

4. An assembly as in claim 1, claim 2 or claim 3 further characterised by the antenna array elements being adjacent to at least one other antenna array element.

5. An assembly as in claim 1, claim 2, claim 3 or claim 4 further characterised by the antenna array elements being aligned.

6. An assembly as in claim 1, claim 2, claim 3, claim 4 or claim 5 further characterised by the antenna array elements being adapted to effect reception or transmission of High Frequency electromagnetic radiation the frequency of which is within the range of 2 to 40 megahertz.

7. A method of re-arranging connections to outputs to or inputs from controlled beam weighting circuitry means associated with individual antenna array elements including the steps of:

effecting reception or transmission of electromagnetic radiation with a plurality of antenna array elements;

processing with one or more processing means signals received by the processing means for transmission to an antenna array element or received from an antenna array element;

selectively and controllably, with a plurality of controlled beam weighting circuitry means, adjusting either or both the phase and amplitude of signals received from or sent to the connected element where each element has one of the controlled beam weighting circuitry means associated with and connected to it;

selectively and controllably connecting one or more processing means to the controlled beam weighting circuitry means so that any one control beam weighting circuitry means is connected to one processing means;

and

selectively changing the processing means to which any one of the controlled beam weighting circuitry means is connected.

8. A method as in claim 7 including the step of effecting either or both antenna array splitting and antenna array interleaving such that each of the said sub-arrays is either a split array or an interleaved array.

9. A method as in claim 7 or claim 8 further characterised by forming each antenna array element substantially identical to one another.

10. A method as in claim 7, claim 8 or claim 9 further characterised by placing the antenna array elements adjacent to at least one other antenna array element.

11. A method as in claim 7, claim 8, claim 9 or claim 10 further characterised by aligning the antenna array elements in a line.

12. A method as in claim 7, claim 8, claim 9, claim 10 or claim 11 further characterised by effecting with the antenna array elements reception or transmission of High Frequency electromagnetic radiation the frequency of which is within the range of 2 to 40 megahertz.

13. An assembly including a plurality of antennae and associated connection circuitry, combining means adapted to combine the antennae into a single antenna array or a plurality of antenna sub-arrays, the combining means being further characterised by being adapted so that the combination of individual antennae forming the antenna array or antenna sub-arrays are selectable and changeable as desired, and one or more processing means adapted to be connected through the combining means to the connection circuitry and provide an output or an input for each antenna sub-array or for the antenna array.

14. An assembly as in claim 13 where the sub-arrays are either or both split or interleaved sub-arrays of the antenna array and for each sub-array there is a signal station.

15. An apparatus as in claim 14 where the combining means is adapted to selectively switch the connection circuitry of each antennae to one of a number of processing means and the selective switching can be changed.

16. A method of re-arranging outputs to or inputs from antennae including the steps of combining with combining means a plurality of antennae and associated connection circuitry into a single antenna array or a plurality of antenna sub-arrays, changing as desired the combination of individual antennae forming the antenna array or antenna sub-arrays, and providing through processing means an output or an input for each antenna sub-array or for the antenna array.

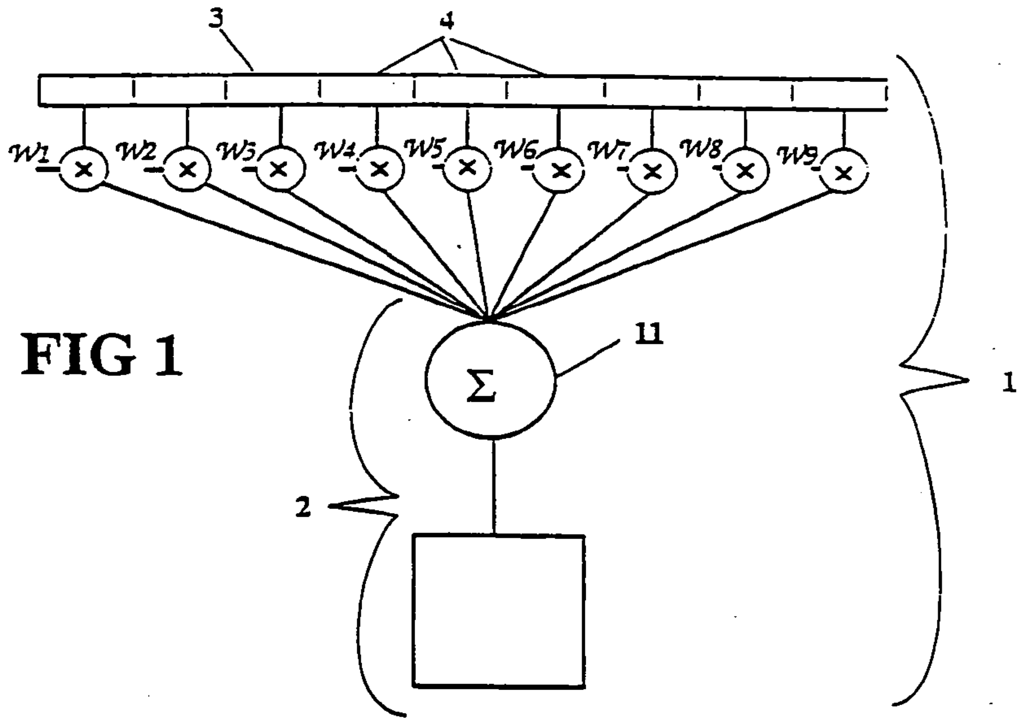
17. A method as in claim 16 where the sub-arrays are formed by either or both splitting or interleaving the antenna array and forming for each sub-array a signal station.

18. A method as in claim 17 where the step of combining includes selectively switching the connection circuitry of each antennae to one of a number of processing means and the step of changing the combination including selective changing of the selective of the connection circuitry.

19. A method of re-arranging outputs to or inputs from array elements to form an antenna array of a first signal station out of antenna sub-arrays of a plurality of other signal stations, or to form a plurality of antenna sub-arrays of a plurality of signal stations from an antenna array of another signal station including the step of selectively and changeably combining the array elements to form the first or other signal stations.

20. A method as in claim 19 where the signal stations of the antenna sub-arrays are formed from the antenna array of the first signal station by either or both splitting or interleaving the antenna array.

21. A method as in claim 20 where some of the sub-arrays are formed by interleaving the antenna array of the first signal station and others are formed by splitting the antenna array of the first signal station.


3
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W1
W2
W3
W4
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W8
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1
2

FIG 1

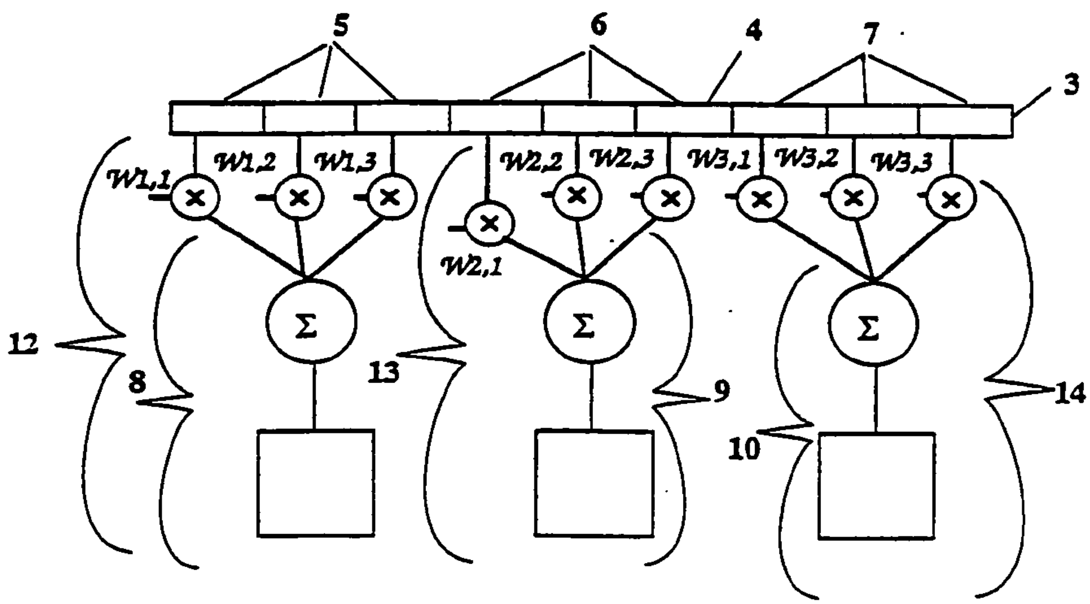
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FIG 2

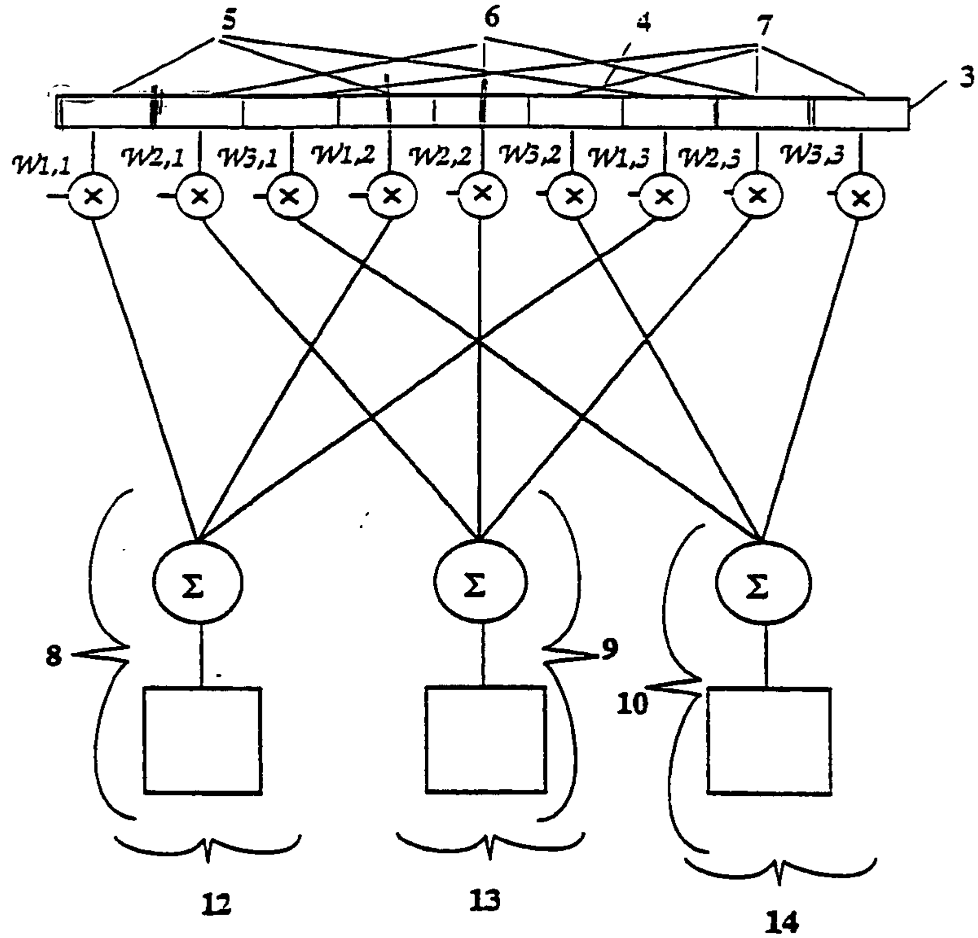

FIG 3

INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent classification (IPC) or to both National Classification and IPC

Int. Cl.[5] H01Q 21/28, 21/30

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC	H01Q 21/28, 21/30, 25/04

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

AU : IPC as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category*	Citation of Document, [11] with indication, where appropriate of the relevant passages [12]	Relevant to Claim No [13]
X	EP,A, 410725 (MINNESOTA MINING AND MANUFACTURING COMPANY) 30 January 1991 (30.01.91 column 2 lines 13-28, column 3 line 25 - column 7 line 51.	13,16
A	WO,A, 91/01620 (SCIENTIFIC ATLANTA, INC.) 2 June 1989 (02.06.89) entire document	
A	GB,A, 1160696 (COMPAGNE FRANCAISE THOMSON HOUSTON-HOTCHKISS BRANDT) 6 August 1969 (06.08.69) entire document	

* Special categories of cited documents : [10]

"A" Document defining the general state of the art which is not considered to be of particular relevance
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
7 July 1992 (07.07.92)	31 Aug 1992 (31.08.92)
International Searching Authority	**Signature of Authorized Officer**
AUSTRALIAN PATENT OFFICE	R. CHIA